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Evaluation of the potential effects of ingredients added to cigarettes. Part 2: Chemical composition of mainstream smoke. Food and Chem. Toxicol., 40: 93-104 (2002).

40. Schlotzhauer, W.S., Chortyk, O.T. Recent advances in studies on the pyrosynthesis of cigarette smoke constituents. J. Anal. Appl. Pyrol., 12: 193-222 (1987).

41. Secretary of State for Health. Voluntary agreement on the approval and use of new additives in tobacco products in the U.K., 7 March 1997.

42. Seeman, J.I., Dixon, M., Haussman, H-J. Acetaldehyde in mainstream tobacco smoke: formation and occurrence in smoke and bioavailability in the smoker. Chem. Res. Toxic., 15: 1331-1350 (2002).

43. Smith, G. Unpublished results, British American Tobacco, U.K. (2003).

44. Stein, Y.S., Antal, Jr., M.J. A study of the gas-phase pyrolysis of glycerol. J. Anal. Appl. Pyrol., 4: 283-296 (1983).

45. United States Public Health Service. Smoking and health. A report of the Surgeon General. DHEW Publication No. PHS 79-50066 PHS 79-50066, pp. 63-64 (1979).

46. United States Public Health Service. The health consequences of smoking. The changing cigarette. A report of the Surgeon General. DHHS Publication No. PHS 81-50156, pp. 51-52 (1981).

47. Vanscheeuwijck, P.M., Teredesai, A., Terpstra, P.M., Verbeeck, J., Kuhl, P., Gerstenberg, B., Gebel, S., Carmines, E.L. Evaluation of the potential effects of ingredients added to cigarettes. Part 4: Subchronic inhalation toxicity. Food and Chem. Toxicol., 40: 113-131 (2002).

48. White, R., Yeats, A., Skipworth, G. Tables for statisticians. Stanley Thornes (Publishers) Ltd., Cheltenham, U.K., pp 13-14, Third edition (1979).

49. World Health Organization (WHO) Monograph. Advancing knowledge on regulating tobacco products. WHO, Geneva, Switzerland, pp 40-46 (2001).

50. Wynder, E.L., Hoffmann, D. Tobacco and tobacco smoke. Studies in experimental carcinogenesis. Academic Press, New York and London, pp. 484-488, 526-528, 628 (1967).

INFLUENCE OF CIGARETTE DESIGN ON HUMAN SMOKING BEHAVIOUR AND SENSORY RESPONSES.

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ABSTRACT

A brief description of the main sensory effects of mainstream smoke is presented. The anatomical sites of origin of the sensory responses are related to the sequence of events in the puffing and inhalation phases of the smoking cycle. Some key sensations, such as mouthfeel, are initiated from the mouth region during the puffing phase, and are believed to be important factors in influencing puff volume. The intensity of the mouthfeel sensation is determined by the 'tar' yield rather than the nicotine yield of the cigarette.

Other key sensations, including the impact sensation, are initiated from the pharyngeal/laryngeal region during the post-puff inhalation phase of the smoking cycle. Nicotine yields have a large influence on the intensities of the impact sensation but do not appear to control puff volume. The implications of the separate effects of 'tar' and nicotine on puffing behaviour and sensory responses are discussed with respect to the development of low-'tar', maintained-nicotine yield cigarettes.

Reductions in the FTC 'tar' and nicotine yields of cigarettes decrease the intensities of key sensations such as mouthfeel, flavour amplitude, impact and irritation. These appear to be consistent with reduced absolute amounts of 'tar' and nicotine delivered to the smoker, rather than a reduction in the concentration of 'tar' and nicotine due to compensatory increases in puff volume.

1. INTRODUCTION

Tobacco smoke is known to induce a range of sensory responses including gustation, olfaction and common chemical sense mediated responses such as mouthfeel

impact, irritation, etc. The importance of the sensory properties of smoke was addressed by Brill in 1922 (1). Brill discussed the concept of learned taste preferences and stated that tobacco, like many other substances (e.g. salt, refined sugar, chocolate), is consumed for taste rather than for nutritional value. He also claimed that these substances are not merely enjoyed when they are readily available but are actively sought after, sometimes at considerable inconvenience. Brill described smoking as a means of taking into the body a substance which excites sensory organs in the lips, mouth and throat and which provides sensations of touch, taste, heat and irritation.

The sensory properties of cigarette smoke enable smokers to reliably distinguish between and amongst cigarettes of different blend styles e.g. Ramond *et al.* in 1950 (2), Prothro in 1953 (3). It has also been suggested that differences in the sensory properties of cigarettes may be important factors influencing the compensatory smoking behaviour responses frequently observed when smokers switch from higher to lower yield cigarettes.

The aims of this paper are to discuss:

1. The key sensory responses to tobacco smoke, in terms of anatomical sites of origin, and their onset during the puff and inhalation phases of smoking.
2. The influence of smoke yields determined by the standard US Federal Trade Commission (FTC) or International Standards Organisation (ISO) machine-smoking methods on the magnitudes of the key sensory responses.
3. The role of nicotine in the sensory responses to cigarette smoke.
4. The importance of sensory factors in 'compensatory' smoking behaviour.
5. The influence of cigarette design features, e.g. 'tar' to nicotine ratios, filter ventilation and cigarette pressure drop, on the sensory properties of cigarettes.

2. KEY SENSORY RESPONSES AND SITES OF ORIGIN

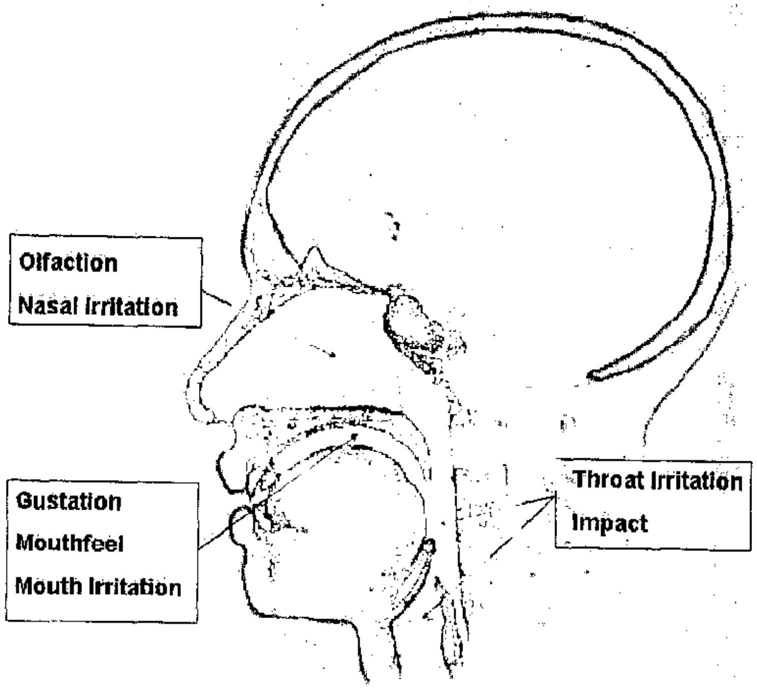
The main sensory responses to mainstream cigarette smoke can be classified as follows:

- Gustation (taste) – sensations arising from the mouth region caused by the stimulation of specialised sensory cells (taste buds) primarily located on the tongue.
- Olfaction (aroma) – sensations arising from the olfactory region located in the roof of the nasal cavities. The olfactory sensations are mediated *via* olfactory receptors sited within the olfactory epithelium.

- Flavour – the sensation of flavour is a summation of the olfactory and gustation responses. Flavour characteristics may include simple gustation notes such as sweet and bitter, and more complex olfactory responses such as floral, woody, nutty, etc.
- Common Chemical Sense – these cover a group of sensations arising from the mouth, nose, and throat (oro-pharynx and larynx) regions. The sensations are mediated *via* sensory nerve endings located within the epithelial tissues in these regions. They are often referred to as 'trigeminal sensations' because many of the sensory receptors in the mouth and nose region are linked to the central nervous system (CNS) by the trigeminal nerve. However, other nerve pathways are involved in the common chemical sense response to tobacco smoke including, for example, the superior laryngeal and glossopharyngeal nerves. The tobacco industry has developed sensory vocabulary in order to describe the various common chemical sense responses to tobacco smoke and these include:
    - Irritation (tingling, peppery) sensations within the mouth, nose and throat.
    - The sensation of body or mouthfeel within the mouth region.
    - Sensations of coolness or warmth within the mouth and throat regions.
    - The sensation of impact in the throat region during smoke inhalation.

The locations of the key sensory responses are shown in the diagram in Figure 1.

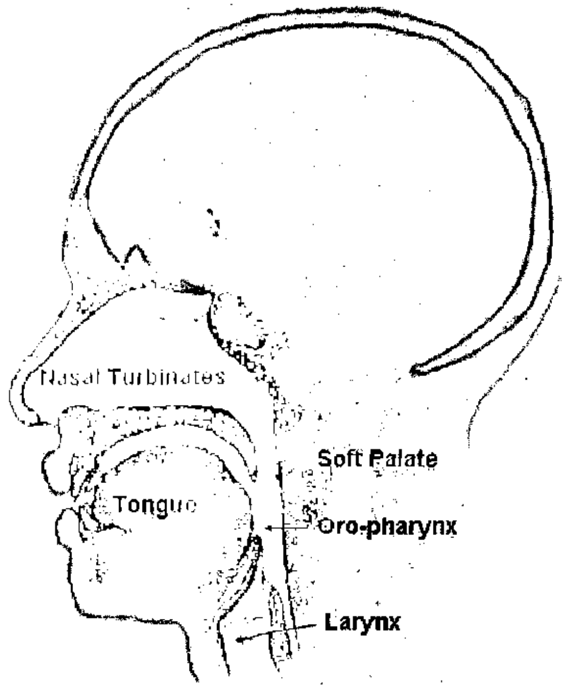
Figure 1 : Anatomical sites of key sensory responses



3. THE PUFF AND INHALATION PHASES OF SMOKING AND SEQUENCE OF SENSORY EVENTS

The majority of cigarette smokers will recognise that the action of smoking is a two-phase event; however, many tobacco control scientists fail to recognise the distinction between the puff and inhalation/exhalation phases of the smoking cycle. In 1986, Rodenstein and Stanescu (4) reported a study using a soft tissue X-ray technique to visualise the mouth and upper airway during the puffing phase of the smoking cycle. They observed that the soft palate (see Figure 2) contracts and physically seals the mouth from the oro-pharynx during the puff process.

Figure 2 : Key anatomical features of the mouth and upper airway



The tongue and lower jaw are depressed and a negative pressure is created within the mouth cavity. The pressure gradient between the 'sealed' mouth and the atmosphere causes air movement through the cigarette. Smoke enters the mouth during this puffing process, and access to the throat (oro-pharynx and larynx) or nasal regions is prevented by the closed soft palate. Consequently, the mouth is the only site available for eliciting sensory responses during the puff process.

Shortly after the end of the puff, typically in less than a second, the soft palate relaxes and adopts the mid position depicted in Figure 2. This is followed by the inhalation/exhalation process, in which the smoke is mixed with inspired air entering the mouth and is swept from the oral cavity, *via* the pharynx and larynx, into the lungs (5). Sensations arising from the oro-pharynx and larynx, i.e impact and throat irritation, occur as components of smoke contact the sensory nerve endings in this region during the inhalation process. Volatile components of

smoke will also diffuse to the olfactory region within the nose after the p is completed and the soft palate is relaxed. These will give rise to tl ar sensations that form a major component of the perceived flavour charac of cigarette smoke.

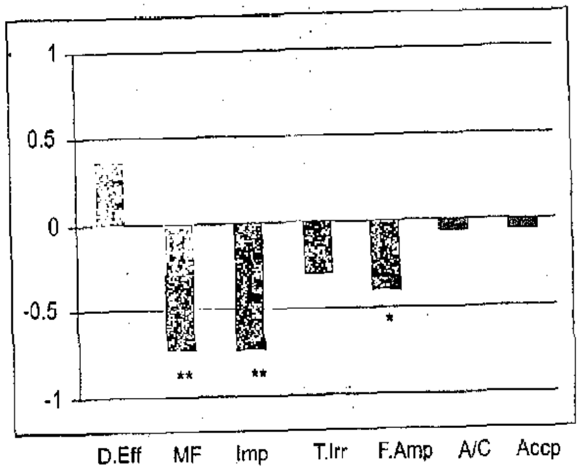
4. THE EFFECTS OF REDUCING 'TAR' AND NICOTINE YIELDS ON THE SENSORY RESPONSE TO CIGARETTE SMOKE

One of the consequences of reducing the 'tar' and nicotine yields of cigarettes i a reduction in the perceived sensory properties of cigarettes (6). At British America Tobacco, we have conducted a number of studies in recent years to investigate th influence of smoke yields on sensory and behavioural responses. Sensory panels comprised of assessors trained in the recognition and amplitude scaling of key sensory properties of tobacco smoke, have been used in many of the stud

One study compared the cigarette design, smoke chemistry and perceived sens differences of a series of eight commercial full-flavour products and their lights variants. Three of the products were from the US market and the other five were from European markets. Blind paired sensory comparisons of each full-flavour and lights variant were conducted using a panel of ten trained assessors. The assessors were each provided with two products (a full-flavour and lights variant from the same brand family). All brand identifiers were masked and one of the products was nominated as the 'control'. The other product was nominated as the 'test' and the assessors were required to rate the sensory properties of the 'test' product relative to the 'control'. An assessment questionnaire was provided and the assessors were asked to tick one of nine category 'boxes' for each sensory attribute. The fifth box was anchored as the 'no difference' response, with four being higher and four being lower than the 'control'. Each paired test was repeated with the test and control products reversed. On completion of the tests, the assessment forms were scored by the panel administrator, expressing the response of the lights product relative to the full-flavour product in each case. A score of zero was given if the assessor rated the lights and full-flavour products as being the same, and scores of +1 to +4 were given for ratings higher than, and -1 to -4 for ratings lower than the full-flavour product. The resulting sensory data were analysed using the non-parametric Wilcoxon matched pairs test.

Figure 3 shows the mean relative scores for a popular US lights product (FTC 'tar' 9.8mg, nicotine 0.71mg) relative to its full-flavour parent brand (FTC tar 14.8mg, nicotine 0.98mg).

Figure 3. The mean sensory responses of a commercial US lights product relative to its full-flavour parent brand. Sensory attributes include Draw Effort (D.Eff.), Mouthfeel (MF), Impact (Imp), Throat Irritation (T.Irr), Flavour Amplitude (F.Amp), Air-cured note (A/C), Acceptability (Accp).

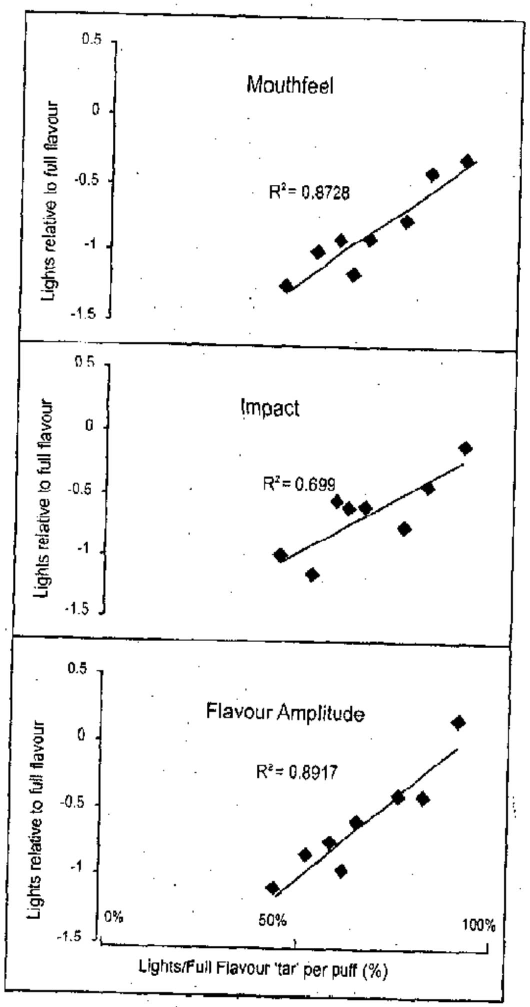


*** denotes significant difference, p<0.05,*
** denotes significant difference, p<0.1, Wilcoxon test*

It is clear from the above figure that the lights variant of the popular US product was perceived as being significantly lower than the full-flavour variant in the sensations of mouthfeel, impact and flavour amplitude. This response is a typical example of the results obtained from our sensory studies of lights versus full-flavour brand variants.

The relationships between the ISO yields of the full-flavour and lights variants and the changes in sensory responses were examined for the eight full-flavour and lights pairs of products. The nicotine-free dry particulate matter (NFDPM, or 'tar') and nicotine yields per puff were measured under ISO conditions for the eight pairs of products and the yields of the lights variants were expressed as a percentage of the yields of the full-flavour parent brand. These were compared with the differences in the sensory profiles of the lights relative to the full-flavour products, i.e. the data shown in Figure 3 but for all eight products. Figure 4 illustrates the relationships between relative 'tar' yields and sensory scores for the attributes mouthfeel, impact and flavour amplitude.

Figure 4. The relationship between sensory properties of lights relative to full-flavour (FF) products and the degree of reduction in 'tar' yield/puff (ISO ...achi smoking conditions)



There was a good relationship between the percentage reduction in the tar yield per puff of the lights relative to full-flavour brands and the reduction in the magnitudes of the sensory attributes, mouthfeel, impact and flavour amplitude. In other words, the larger the reduction in ISO tar yields, the greater the reduction

in the intensities of these sensory attributes. A similar relationship to that shown in Figure 4 was obtained by using ISO nicotine yields instead of 'tar' yields. This is not too surprising as the reductions in ISO tar yields were accompanied by almost equivalent reductions in nicotine yields when moving from the full-flavour to the lights variants of the brands.

5. THE ROLE OF NICOTINE IN THE SENSORY RESPONSES TO CIGARETTE SMOKE

As demonstrated in the previous section, reducing both 'tar' and nicotine yields decreases the intensities of sensory attributes such as mouthfeel, impact and flavour amplitude. However, an understanding of the separate roles of nicotine and tar in the genesis of the sensory responses to cigarette smoke would be useful for the development of low and ultra-low yield products.

In 1990, Kochhar and Warburton (7) measured the puff-by-puff sensory responses obtained from two cigarettes matched in 'tar' yield but differing in nicotine yield. They observed that the higher nicotine yield cigarette produced higher sensory intensities in the throat during cigarette smoke inhalation. Similar findings were reported by Pritchard *et al.* in 1996 (8), who demonstrated that nicotine played an important role in the sensory impact of cigarette smoke. British American Tobacco has recently conducted a smoking behaviour and sensory study in conjunction with the Department of Psychology at the University of Reading, UK (9). This study was aimed at assessing the sensory and behavioural effects of reducing nicotine yields whilst maintaining 'tar' yields and cigarette physical design features at a constant level. A series of experimental cigarettes were manufactured using different combinations of normal and denicotinised tobacco in the tobacco blends. Brief details of the experimental cigarettes are shown in Table 1.

Table 1. NFDPM ('tar'), nicotine and carbon monoxide (CO) yields, filter ventilation levels and cigarette pressure drop values – ISO machine-smoking conditions (1 puff/min, 35ml puff volume; 2s duration, butt length: filter overwrap+3mm)

	Sample A	Sample B	Sample C	Sample D	Sample E
NFDPM ('tar') (mg/cig)	8.7	9.5	8.8	7.7	8.1
Nicotine (mg/cig)	0.81	0.77	0.48	0.22	0.10
CO (mg/cig)	7.3	7.9	7.3	6.6	6.7
Puff count	8.9	9.8	9.8	9.0	8.9
Nicotine : 'tar' ratio	0.093	0.081	0.055	0.029	0.012
Filter ventilation* (%)	52	51	51	51	48
Unencapsulated cigarette pressure drop* (mm H2O)	76.1	77.7	78.7	83.9	76.0

* *Measured at an air flow of 17.5 ml/s*

The experimental samples were assessed by a group of thirteen smokers. All of the smokers were trained in the sensory evaluation of cigarettes. The cigarettes were smoked monadically and the sensory intensities were assessed using a 5-point scale (1 - very low intensity, 5 - very high intensity). A one-way analysis of variance (ANOVA) test was used to determine if any statistically significant differences existed between the samples for each attribute. The mean sensory assessment scores for the group of smokers are shown in Table 2.

Table 2. Mean ± standard deviation sensory evaluation results (n=13 for each sample)

	A	B	C	D	E	p value
ISO-Nicotine yield (mg)	0.81	0.77	0.48	0.22	0.10	NA
Draw effort	2.23±0.70	2.44±0.90	2.79±0.71	2.93±0.90	2.76±0.82	0.180
Mouthfeel	2.79±0.44	2.71±0.44	2.49±0.59	2.22±0.59	2.58±0.72	0.109
Impact	2.33±0.56	2.16±0.76	1.61±0.74	1.22±0.82	1.50±1.06	0.003
Irritation	2.31±0.84	2.15±0.88	1.68±0.81	1.62±0.80	1.82±0.73	0.147
Flavour amplitude	2.80±0.83	2.83±0.61	2.65±0.72	2.41±0.80	2.50±0.86	0.572

NA = not applicable

Reducing the nicotine yield at a constant 'tar' yield produced a statistically significant (p=0.003) reduction in the intensity of the impact sensation but did not significantly influence the intensities of the other sensory attributes measured in the study. These results imply that the nicotine content of cigarette smoke does not influence sensations produced in the mouth during the puff process e.g the sensation of mouthfeel, or the magnitude of the gustation and olfaction response, i.e flavour amplitude. However, the sensation of impact, which is experienced during the inhalation phase of smoking, is influenced by the nicotine content of the cigarette smoke.

It has been suggested that nicotine absorbed from cigarette smoke into the systemic circulation stimulates nicotinic receptors in the brain and gives rise to the sensation of 'impact' or 'hit' (10). However, this mode of action is unlikely, as the impact sensation occurs almost instantaneously during cigarette smoke inhalation, while there would be a minimum latency period of around 10 seconds before the nicotine inhaled in a bolus of cigarette smoke could be absorbed and transported to receptor areas of the brain. The timing of the impact sensation suggests that nicotine is acting peripherally rather than centrally. In 1998, Rose *et al.* (11) hypothesised that nicotinic receptors on peripheral nerve endings in the respiratory tract may be involved in some of the sensory effects of smoking. In 2001, Pankow (12) suggested that the strength of the impact sensation is related to the amount of nicotine evaporating from smoke particles in the throat region. This information, together with data from electrophysiological studies in animals that show tobacco smoke stimulates rapidly-adapting afferent receptors in the bronchi (13) and larynx (14), implies that the sensation of impact is initiated by the stimulation of afferent nerve endings in the upper airway by nicotine.

6. THE IMPORTANCE OF SENSORY FACTORS IN THE SMOKING BEHAVIOUR RESPONSE TO LOW 'TAR AND NICOTINE YIELD CIGARETTES

Smokers can vary the size and duration of puffs taken from a cigarette. Changes in puff volume can have a large effect on the deliveries of smoke components and magnitude of the sensory response to cigarette smoke. It is believed that an increase in puff volume is the main mechanism of smoker behaviour compensation when smokers switch from higher to lower yield cigarettes (15).

It has been hypothesised that the nicotine content of smoke may be responsible for influencing the volume and duration of the puff *via* a direct action of nicotine in the central nervous system. This is frequently referred to as the nicotine titration

or regulation hypothesis (16). Many of the published studies investigating smoker compensation and the nicotine titration hypothesis have not attempted to separate the effects of nicotine and 'tar' and have thus ignored the potential role of the reduction in 'tar' yield in the smoking behaviour response to reduced 'tar' and nicotine yield cigarettes. However, there were a few studies conducted in the 1970s and early 1980s that attempted to separate the effects of 'tar' and nicotine on aspects of smoking behaviour and these produced conflicting results. In 1970, Goldfarb *et al.* (17) reported an assessment of the smoking rates and psychological effects of smoking lettuce leaf cigarettes with and without added nicotine. They observed that varying the nicotine yield of the lettuce leaf cigarettes had no effect on cigarette consumption rates but influenced the perceived strength of the cigarettes. The higher nicotine yield cigarettes were rated as being stronger than the lower or zero nicotine-yield cigarettes. The authors concluded that "the habit itself often exhibits functional autonomy from the physiological effects of nicotine".

In 1978, Dunn and Freiesleben (18) reported a study in which they had experimentally enhanced the nicotine yields of cigarettes by adding nicotine citrate to the tobacco blend. Nicotine enhancement did not influence daily cigarette consumption rates, puff counts, puff durations or relative puff volumes. In 1981, Stepney (19) observed reductions in mouth-level exposure to 'tar' when smokers switched to either a low-'tar'/ low-nicotine cigarette or a low-'tar'/ medium-nicotine cigarette. However, there was no evidence that the reduction in 'tar' exposure was greater with the low-'tar'/ medium-nicotine cigarette than with the low-'tar'/ low-nicotine cigarette. Indeed, the smoking behaviour responses in terms of puff numbers and puff volumes were similar for the two low-'tar' cigarettes despite the difference in the nicotine yields of the two cigarettes. Thus, Stepney (19) suggested that smokers may modify their behaviour in response to sensory cues produced by 'tar', and that the amount of smoke taken from a cigarette may be affected by a complex interaction between the sensory effects of 'tar' and nicotine.

In contrast to these above three studies, Herning *et al.* in 1981 (20) and Gust and Pickens in 1982 (21) both reported that changing nicotine yields independently of 'tar' yields influenced puffing behaviour. Both these studies used experimental, unfiltered cigarettes produced by the University of Kentucky, which had very high 'tar' yields (around 25-30mg) and nicotine yields of 0.4mg, 1.2mg and 2.5mg. Herning *et al.* (20) reported that the puff volume was higher on the lowest nicotine yield sample, but that puff number, puff duration and inter-puff interval were similar across the three samples in the twenty four smokers who were studied.

Similarly, Gust and Pickens (21) reported that for the six smokers in their study, increasing nicotine yield was associated with a decrease in average puff volume, puff duration and puff count.

More recently, there have been a number of studies comparing commercially manufactured cigarettes made from denicotinised tobacco with those made from conventional tobacco in the attempt to differentiate the effects of nicotine and 'tar' yields on smoker compensation. In 1992, Robinson *et al.* (22) reported a comparison of two cigarettes, which were matched for 'tar' yield (around 9mg) but differing radically in nicotine yield (0.08mg vs. 0.6mg). They found no differences in puffing behaviour between the two cigarettes. About the same time, in 1993 Hasenfratz *et al.* (23) conducted a smoking behaviour and smoke uptake study using three cigarettes. One was a commercial cigarette with a tar yield of 10.1mg and a nicotine yield of 0.81mg. The second product was similar in 'tar' yield to the commercial product, but incorporated denicotinised tobacco and had a nicotine yield of only 0.08mg. The third cigarette was a commercial product with a 'tar' yield of 1.83mg and a nicotine yield of 0.22mg. Puffing intensities were similar for the commercial and denicotinised 10mg 'tar' yield cigarettes. Thus, there was no evidence that the reduction in nicotine yield was associated with an increase in puffing intensity.

These researchers also measured nicotine intake / nicotine yield, and CO intake / CO yield ratios as indices of compensation for the three cigarettes. The commercial and denicotinised products produced similar ratios, but the ratios were double with the 1.83mg 'tar' cigarette. Consequently, Hasenfratz *et al.* (23) concluded that gustatory and olfactory sensations arising from cigarette smoke 'tar' play a greater role in the regulation of smoking behaviour than was previously believed.

In the same laboratory, Baldinger *et al.* in 1995 (24) extended the work of Hasenfratz *et al.* by measuring more extensive indices of puffing topography. They observed that smokers took similar total puff volumes from the commercial and denicotinised lights cigarettes but increased total puff volume when smoking the ultra-lights cigarette. Thus, they concluded that puff volumes were influenced by changes in the 'tar' yield, but not the nicotine yield of the cigarette.

In our recent study (9), investigating the influence of changing nicotine yields on smoking behaviour and sensory responses, the 'tar' yields and physical characteristics of the test cigarettes were held relatively constant. Varying the relative amounts of commercial and denicotinised tobacco in the blends produced a wide range of

nicotine yields across the test samples (0.10mg/cig to 0.81mg/cig). However, these changes in nicotine yields at a constant 'tar' yield of approximately 8-9mg/cigarette were not associated with significant changes in puff counts, volumes, durations, pressures or intervals. Our observations imply that these puffing variables are not controlled by the nicotine yield of the cigarette. Thus, they are consistent with the findings and conclusions of Stepney (19), Hasenfratz *et al.* (23) and Baldinger *et al.* (24).

Several researchers have investigated factors that influence human puff volumes. Much of this work has focused on changes in puff volume (and duration) from early to late puffs on a single cigarette. It is clear that for the majority of smokers, puff volumes and durations decline as the cigarette rod is consumed (25 -31).

In 1989, Guyatt *et al.* (31) observed that the extent to which smokers reduced their puff volumes from early to late puffs was correlated with the magnitude of the increase in puff volume following a switch to lower yield products. This implied that factors responsible for 'controlling' puff volume during the course of smoking a single cigarette were likely to be similar to those responsible for the increase in puff volume observed following a switch to a lower yield product.

Within British American Tobacco, a series of research studies has been conducted aimed at evaluating the factors responsible for the decline in puff volume and duration as the cigarette is consumed (32). The findings show that the magnitudes of puff volume and duration are influenced by mouth sensations, primarily mouthfeel, produced during the puffing process and that this mechanism is mediated by components of 'tar' and not nicotine. As previously discussed, sensory events occurring after the end of the puff, e.g. the sensation of impact during the inhalation of cigarette smoke, are influenced by the nicotine content of smoke but do not appear to influence the volumes and durations of subsequent puffs.

The separate effects of 'tar' and nicotine on the sensory effects of cigarette smoke, experienced initially during the puffing process, and subsequently during the inhalation of smoke, are important when one considers the modification of 'tar'-to-nicotine ratios of mainstream smoke. The nicotine regulation or titration hypothesis led to a proposal for the development of cigarettes reduced in 'tar' yield but with maintained nicotine yields. It was believed that maintaining nicotine yields of low-'tar' cigarettes at levels associated with full-flavour cigarettes would minimise smoker compensation and thereby present a 'safer' alternative to the conventional low-'tar'/low-nicotine cigarette (16, 33, 34). As previously mentioned,

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products (38 - 41). In 2001, Shiffman *et al.* (41) specifically referred to lighter and smoother sensations in the throat and chest regions. Recently, Kozlowski and co-workers (42, 43) stated that this lighter sensory response supports the consumer perception that lower 'tar' cigarettes deliver less 'tar' and nicotine than higher 'tar' cigarettes. The authors suggest that the introduction of ventilation can reduce the perceived sensory responses without producing a reduction in the delivery of 'tar' and nicotine to the smoker. They claim that filter ventilation dilutes smoke with air, and smokers respond to the reduced nicotine delivery that results from air dilution by increasing their puff volume. They further claim that:

a) The increase in puff volume may result in the smoker obtaining similar nicotine yields from a high FTC yield unventilated product and a lower FTC yield ventilated product.
b) The larger puff from the ventilated cigarette will feel 'lighter' to the smoker than if they had taken a smaller more concentrated puff of equivalent yield from an unventilated or less ventilated cigarette.
c) The smoke from a ventilated cigarette will be more 'air cooled' and hence milder than the smoke from an unventilated cigarette
d) The addition of filter ventilation reduces the draw resistance of the cigarette and thereby facilitates the taking of larger volume puffs.

Kozlowski and O'Connor (43) subsequently formed the opinion that cigarette filter ventilation is a defective design and should be banned as a means of reducing machine-smoked yields.

The final part of this paper is an attempt to address the above concerns about filter ventilation and perceived mildness.

First, the concept of filter ventilation introducing an air-cooling effect on the smoke implies that smoke exiting the filter of an unventilated cigarette is at a temperature higher than ambient air. This is not consistent with published data that shows cigarette smoke exits the filters of unventilated and ventilated cigarettes at or around ambient temperature (44). Consequently, the introduction of room air through the filter vents will not 'air-cool' the smoke. Thus it is unlikely that the perception of mildness is mediated *via* a smoke temperature effect within the mouth and upper airway.

Secondly, if, as suggested by Kozlowski *et al.* (42, 43), filter ventilation results in a smoker taking a larger puff volume and obtaining the same amount of 'tar' and

nicotine than they had obtained from an unventilated cigarette, then the smoke entering the mouth from the ventilated cigarette would be less concentrated than the smoke from the unventilated cigarette. This concentration reduction in the absence of an absolute amount reduction may result in a reduced sensation in the mouth during the puffing process e.g. the sensation of mouthfeel. However, as previously discussed, many key 'strength'-related sensations, e.g. impact and throat irritation, are not initiated during the puff process where puff volume dilution may be a factor. These sensations are initiated during the inhalation process. A dilution effect during the puff ceases to be relevant at this point, because the smoke components will experience dilution in the residual volume of the mouth with a much larger volume of air during inhalation, typically 400 – 1000 ml (45). Thus any concentration effect in the puff will be swamped by the much larger dilution processes occurring as inhaled air is mixed with the smoke in the mouth prior to its transport to the sites of the 'inhalation' sensations. Consequently, a reduction in the intensity of the sensation of impact during inhalation is far more likely to arise as a result of a lower nicotine delivery than as a consequence of a ventilation-induced, air-dilution effect in the puff.

Finally, Kozlowski and O'Connor (43) are correct in saying that, other things being equal, the introduction of filter ventilation results in a reduction in cigarette draw resistance or pressure drop. This effect has been discussed in quantitative terms by several authors in the scientific literature and summarised by Norman (46). A reduction in cigarette draw resistance can also lead to an increase in puff volume (47, 48). However, many lights variants of cigarette brands incorporate other delivery reduction features in addition to filter ventilation. These include higher efficiency filters, more highly porous cigarette paper, the use of expanded tobacco, etc. An increase in the efficiency of the filter is usually associated with an increase in the pressure drop of the filter, thus a ventilation-induced reduction in draw resistance may be offset by the use of a higher pressure drop filter. Therefore, the pressure drop and puff volume facilitation criticism of the use of filter ventilation (43) cannot be applied to all ventilated low-yield cigarettes.

The full-flavour and lights brands sensory comparisons discussed in Section 4 of this paper used three pairs of commercial products from the US market. Filter ventilation levels and pressure drop values for the three pairs of US products are shown in Table 3.

Table 3 : Pressure drop and filter ventilation values for the three pairs of US brands

	Filter Ventilation* (%)	Filter pressure drop (bound)*(mm H2O)	Cigarette pressure drop (open)*(mm H2O)
Brand A regular	11	69	109
Brand A lights	23	98	122
Brand B regular	8	60	114
Brand B lights	19	97	128
Brand C regular	20	76	122
Brand C lights	24	85	116

**Measured at an air flow of 17.5 ml/s*

All three brands used modest increases in the levels of filter ventilation in their lights variants. Higher pressure drop filters were used in addition to the increased ventilation levels. The net result, in terms of cigarette draw resistance, was that the pressure drop was higher for the lights than for the regular variants in two of the brands. The lights variant of brand C was marginally lower in pressure drop than the full-flavour variant.

Sensory intensities were lower for the lights variants in all three of the US light vs. regular paired comparison tests (the results shown earlier in Figure 3 refer to brand A). It is clear that the milder sensory properties of these lights variants cannot be explained by the ventilation/pressure drop argument.

It can be concluded that reductions in the FTC 'tar' and nicotine yields of cigarettes decrease the intensities of key sensations such as mouthfeel, flavour amplitude, impact and irritation. These appear to be consistent with reduced absolute amounts of 'tar' and nicotine delivered to the smoker, rather than no difference in absolute deliveries but a reduction in the concentration of 'tar' and nicotine due to compensatory increases in puff volume mediated *via* filter ventilation and cigarette pressure drop effects.

REFERENCES

1. Brill, A.A. Tobacco and the individual. Int. J. Psychoanalysis, 3: 430-440 (1922).

2. Ramond, C.K., Rachal, L.H., Marks, M.R. Brand discrimination among cigarette smokers. J. Appl. Psychol., 34: 282-284 (1950).

3. Prothro, E.T. Identification of American, British and Lebanese cigarettes. J. Appl. Psychol., 37(1): 54-56 (1953).

4. Rodenstein, D.O., Stanescu, D.C. Pattern of inhalation of tobacco smoke in pipe, cigarette, and never smokers. Am. Rev. Respir. Dis., 132: 628-632 (1985).

5. Fairweather, F.A. The possible role of factors other than nicotine in compensatory smoking. Wald, N. and Froggatt, P. (eds). Nicotine and the Low Tar Programme. Oxford University Press, Oxford, pp 212-219 (1989).

6. Cain, W.S. Sensory attributes of cigarette smoking. Gori, G.B. and Bock F.G. (ed.s). Banbury Report 3: A safe cigarette? Cold Spring Harbor Laboratory, New York (1980).

7. Kochhar, N., Warburton, D.M. Puff-by-puff sensory evaluation of a low to middle tar, medium nicotine cigarette designed to maintain nicotine delivery to the smoker. Psychopharmacology, 102: 343-349 (1990).

8. Pritchard, W.S., Robinson, J.H., Guy, T.D., Davis, R.A., Stiles, M.F. Assessing the sensory role of nicotine in cigarette smoking. Psychopharmacology, 127: 55-62 (1996).

9. Dixon, M., Kochhar, N., Prasad, K., Shepperd, C.J. and Warburton, D.M. The influence of changing nicotine to tar ratios on human puffing behaviour and perceived sensory response. Psychopharmacology, paper accepted for publication (2003).

10. Bates, C., McNeil, A., Jarvis, M., Gray, N. The future of tobacco product regulation and labelling in Europe: implication for the forthcoming European Union Directive. Tobacco Control, 8: 225-235 (1999).

11. Rose, J., Westman, E., Behn, F., Johnson, M., Goldberg, J. Blockade of smoking satisfaction using the peripheral nicotinic antagonist trimethaphan. Pharmacol. Biochemistry and Behavior, 62(1): 165-172 (1998).

12. Pankow, J.F. A consideration of the role of gas/particle partitioning in the deposition of nicotine and other tobacco smoke compounds in the respiratory tract. Chem. Res. Toxicol., 14: 1465-1481 (2001).

13. Dixon, M., Richardson, P., Stransky, A., Szereda-Przestaszewska, M., Widdicombe, J.G. Changes in laryngeal calibre due to inhalation of dust. Revue de L'Institut d'Hygiène des Mines, 29(2): 55-58 (1974).

14. Boushey, H.A., Richardson, P.S., Widdicombe, J.G., Wise, J.C.M. The response of laryngeal afferent fibres to mechanical and chemical stimuli. J. Physiol., 240: 153-175 (1974).

15. Scherer, G. Smoking behaviour and compensation: a review of the literature. Psychopharmacology, 145:1-20 (1999).

16. Russell, M.A.H. Low tar, medium nicotine cigarettes: a new approach to safer smoking. Brit. Med. J., 1: 1430- 1433 (1976).

17. Goldfarb, T.L., Jarvik, M.E., Glick, S.D. Cigarette nicotine content as a determinant of human smoking behaviour. Psychopharmacologia, 17: 89-93 (1970).

18. Dunn, P.J., Freiesleben, E.R. The effects of nicotine-enhanced cigarettes on human smoking parameters and alveolar carbon monoxide levels. Thornton, R.E. (ed) Smoking Behaviour: physiological and psychological influences. Churchill-Livingstone, Edinburgh, pp 195-202 (1978).

19. Stepney, R. Would a medium nicotine, low tar cigarette be less hazardous to health? Brit. Med. J., 283: 1292-1303 (1981)

20. Herning, R.I., Jones, R.T., Benowitz, N., Mines, A.H. Puff volume increases when low nicotine cigarettes are smoked. Brit. Med. J., 283: 187-189 (1981).

21. Gust, S.W., Pickens, R.W. Does cigarette nicotine yield affect puff volume? Clin. Pharmacol. Ther., 32: 418-422 (1982).

22. Robinson, J.H., Pritchard, W.S., Davis, R.A. Psychopharmacological effects of smoking a cigarette with typical 'tar' and carbon monoxide yields but minimal nicotine. Psychopharmacology, 108: 466-472 (1992).

23. Hasenfratz, M., Baldinger, B., Bättig, K. Nicotine or tar titration in cigarette smoking behaviour? Psychopharmacology, 112: 253-258 (1993).

24. Baldinger, B., Hasenfratz, M. and Battig, K. Switching to ultra low nicotine cigarettes: effects of different tar yields and blocking of olfactory cues. Pharm. Biochem. Behav., 50(2): 223-239 (1995).

25. Chait, L.D. and Griffiths, R.R. Differential control of puff duration and interpuff interval in cigarette smokers. Pharm. Biochem. Behav., 17: 155-158 (1982).

26. Nemeth-Coslett, R. and Griffiths, R.R. Determinants of puff duration in cigarette smokers: Part I. Pharm. Biochem. and Behav., 20: 965-971 (1984).

27. Nemeth-Coslett, R. and Griffiths, R.R. Determinants of puff duration in cigarette smokers: Part II. Pharm. Biochem. Behav., 21: 903-912 (1984).

28. Nemeth-Coslett, R. and Griffiths, R.R. Effects of cigarette rod length on puff volume and carbon monoxide delivery in cigarette smokers. Drug and Alcohol Dependence, 15(1/2): 1-13 (1985).

29. Chait, L.D., Russ, N.W., Griffiths, R.R. Effects of graded smoke inhalation on subsequent smoking behaviour. Addictive Behaviours, 10: 273-280 (1985).

30. Buzzi, R., Nil, R., Bättig, K. Development of puffing behaviour along burning time of a cigarette - No relation to alveolar inhalation or nicotine delivery of the cigarettes? Psychopharmacology, 86: 102-107 (1985).

31. Guyatt, A.R., Kirkham, A.J.T., Baldry, A.G., Dixon, M. and Cumming, G. How does puffing behaviour alter during the smoking of a single cigarette? Pharm. Biochem. Behav., 33: 189-195 (1989).

32. Dixon, M., Reeves, N., Saunders, P., Shepperd, C.J. Sensory Induced Changes in Puffing Behaviour. Proceedings of the CORESTA Smoke and Technology Groups Joint Meeting, Brighton, England, October 1998: 39-51 (1998).

33. US Department of Health and Human Services. The Health Consequences of Smoking. The Changing Cigarette: A Report of the Surgeon General (1981).

34. ISCSH. Fourth report of the Independent Scientific Committee on Smoking and Health, Her Majesty's Stationary Office, London. (1988).

35. Armitage, A.K., Alexander, J., Hopkins, R., Ward, C. Evaluation of a low to middle tar/medium nicotine cigarette designed to maintain nicotine delivery to the smoker. Psychopharmacology, 96: 447-453 (1988).

36. Russell, M.A.H. Public Health and levels of nicotine: Should nicotine levels in cigarettes be minimized or maximized. Ferrence, R., Slade, J., Room, R. and Pope, M. (eds). American Public Health Association, Washington pp 265-284 (2000).

37. Gori, G.B. Less hazardous smokes? Regulation, Winter 2002-2003: 66-72 (2002).

38. Giovino, G.A., Tomar, S.L., Reddy, M.N., Peddicord, J.P., Zhu, B., Escobedo, L.G., Eriksen, M.P. Attitudes, knowledge and beliefs about low-yield cigarettes among adolescents and adults. The FTC cigarette test method for determining

tar, nicotine and carbon monoxide yields of US cigarettes. Report of the NCI Expert Committee. Monograph 7. Washington: US Department of Health and Human Services, National Cancer Institute, pp 39-53. (1996).

39. Kozlowski, L.T., Goldberg, M.E., Yost, B.A., White, E.L., Sweeney, C.T., Pillitteri, J.L. Smokers Misperception of light and ultra light cigarettes may keep them smoking . Am. J. Prev. Med., 15(1): 9-16 (1998)

40. Evans, N. and Joossens, L. Consumers and the changing cigarette, Health Education Authority, London (1999).

41. Shiffman, S., Pillitteri, J.L., Burton, S.L., Rohay, J.M., Gitchell, J.G. Smokers' beliefs about 'light' and 'ultra light' cigarettes. Tobacco Control, 10 (Suppl I): i17-i23 (2001).

42. Kozlowski, L.T., O'Connor, R.J., Sweeney, C.T. Cigarette design. US Department of Health and Human Services, National Institutes of Health. Smoking and Tobacco Control, Monograph 13, Risks associated with smoking cigarettes with low machine-measured yields of tar and nicotine, pp 13-37 (2001).

43. Kozlowski, L.T. and O'Connor, R.J. Cigarette filter ventilation is a defective design because of misleading taste, bigger puffs, and blocked vents. Tobacco Control, 11 (Suppl 1): i40-i50 (2002).

44. Guyatt, A.R. and Baldry, A.G. Puff volume measurement as affected by temperature with various cigarette types and modes of smoking (An *in vitro* study). Beitr. Tabakforsch. Int., 14(2):119-126 (1988).

45. US Department of Health and Human Services. The Health Consequences of Smoking - Chronic Obstructive Lung Disease. Report of the Surgeon General (1984).

46. Norman, A. Cigarette design and materials. Davis, D.L. and Nielsen, M.T. (eds) Tobacco production, chemistry and technology. Blackwell Science, Oxford, Chapter 11b, pp 353-387 (1999).

47. Dunn, P.J. The effects of a reduced draw resistance cigarette on human smoking parameters and alveolar carbon monoxide levels. Thornton, R.E. (ed) Smoking Behaviour: physiological and psychological influences. Churchill-Livingstone, Edinburgh, pp 203-207 (1978).

48. Rawbone, R.G. The act of smoking. Cumming, G. (ed) Smoking and the lung, Plenum Press, pp 77-93 (1984).